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ORIGINAL PAPER

Reproductive phenology of *Calophyllum inophyllum* in Yeppoon, Australia and Meegoda Western Province, Sri Lanka

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Abstract: Reproductive phenology of multiple use native plant *Calophyllum inophyllum* L. was studied in Yeppoon (23°7'60″ S, 150°43'60″ E), northern Australia (southern hemisphere) and in Meegoda (6º18′51″N, 80º31′3″E), Sri Lanka (northern hemisphere). *C. inophyllum* trees in Yeppoon, Australia had relatively shorter flowering periods, shorter floral life spans, longer fruit life spans, smaller flowers and larger fruits compared to those in Meegoda, Sri Lanka. Although the number of flower buds/ inflorescence was comparatively higher in Meegoda, *C. inophyllum* trees in both locations had similar mean number of mature fruits/ cluster due to the higher floral abscission in *C. inophyllum* trees at Meegoda. Despite having a comparatively lower fruit yield (664 000 fruts·ha^{-1}·a^{-1}), *C. inophyllum* trees in Yeppoon had higher kernel weights (2 988.0±853.2 kg·ha^{-1}·a^{-1}) and oil yields (1 332.6±380.5 kg·ha^{-1}·a^{-1}) compared to those in Meegoda.

Key words: *Calophyllum inophyllum, Flowering, Fruiting, Inflorescence, Phenology*

Introduction

Calophyllum inophyllum L. (Clusiaceae) commonly known as Alexandrian laurel, beauty leaf or Domba (in Sri Lanka) is a native Australian coastal tree species that shows wide distribution; from northern Australia and extending throughout Southeast Asia and southern India (Agroforestry Tree Database 2006). It is a medium to large evergreen tree that grows up to 20 m in height with a broad spreading crown of irregular branches. The tree bears a dense canopy of glossy, elliptical leaves, fragrant white flowers, and large round nuts (Friday & Okano 2006). The species has many economic uses. Kernel oil has a high commercial demand for pharmaceutical and cosmetic applications (Agroforestry Tree Database 2006). The timber is durable (density 600–900 kg/m³) and used in light construction and has a competitive market value (Little and Skolmen 1989). Recently anticancer and anti-HIV compounds were reported from *Callophyllum inophyllum* extracts (Patil et al. 1993; Taylor et al. 1994; Spino et al. 1998; Itoigawa et al. 2001; Powar et al. 2007). *Calophyllum inophyllum* seed has 65% inedible oil and has been identified as one of the potential biodiesel feedstock plants (Azam et al. 2005; Sahoo et al. 2006).

Despite its economic potential, *C. inophyllum* is yet to gain due attention in both Australia and Sri Lanka where the species is regarded as native. Available literature on many aspects including reproductive phenology is quite rare. In most parts of the world *C. inophyllum* shows two flowering and fruiting seasons (Little and Skolmen 1989). However, sometimes flowering may occur throughout the year (Foxworthy 1927). In northern Australia *C. inophyllum* trees flower twice, in January and in June (Friday and Okano 2006), but such information is absent for *C. inophyllum* in Sri Lanka.

Plant phenology is an important study area that enriches the understanding about modes of plant growth and development as well as the effects of the environment and selective pressures on reproductive behaviour (Zang et al 2006). Phenological parameters like intensity, duration and overlap are important factors in determining the reproductive effort of a plant (Richards 1986).The flowering of certain plants also signals the most productive period (Richards et al. 1996). It gives an indication about the fruit yield that can be used in yield prediction, which is important in determining the plant's economic potential. Flowering phenology also implies the fitness of a stand (de Jong and Klinkhamer 1991; Ashman and Schoen, 1996; Sabat and Ackerman 1996). Information on the reproductive behaviour and development of fruits is vital in concentrating efforts towards correct harvesting time. In the absence of systematic information, this study was carried out to understand the flowering and fruiting

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cycles of *C. inophyllum* in northern Australia and in Sri Lanka.

Materials and methods

Three eight year old trees from Roslyn bay, Yeppoon (23°7'60″ S, 150°43'60″ E), Australia and three eight year old trees from Meegoda (6°18'51″N, 80°31'3″E), Sri Lanka were selected for the study (Table 1). Sample size had to be limited due to the rareness of even aged healthy trees (n = 3) and the poor population sizes (n = 5) in the selected locations. Observations were made during late December, 2007 up until late April 2008 in Australia and between May and September, 2008 in Sri Lanka. It was also observed that flowering within each country is more or less synchronous.

Table 1: Climatic and soil conditions of selected locations

Provenance	Coordinates	Altitude (m)	Mean Annual Rainfall (mm)	Mean Annual Temperature Max/Min (˚C)	Soil types
Meegoda Colombo	6º18´51˝N, 80º31´3˝E	7-65	2500	30.6/24.1	Red-yellow podzolic with soft and hard laterite and heavy clay soils.
Roslyn Bay Yeppoon	23° 7' 60 S, 150° 43' 60 E	6-8	870.1	25.9/18.5	Rundle, Shallow stony browns and black massive loams and sandy clay loams.

The number of inflorescences was counted after every six days. An extendable ladder was used to reach taller trees. A washable ink marker was used to mark every counted inflorescence to avoid double counting. From each tree, five inflorescences containing flower buds were tagged and diameter of each flower was recorded after every six days until they become mature fruits. In each tree, number of flowers and drupes in twenty inflorescence/clusters was counted. Total number of fruit bearing clusters was also recorded in each tree.

In each selected tree, number of mature fruits in twenty random fruit clusters was also recorded. Number of fruiting seasons/year and the number of flushes (cycles)/season were also noted. Fruit yield per hectare (for 400 trees) was calculated using following formula.

$$\text{Fruit yield}\cdot\text{ha}^{-1}\cdot\text{a}^{-1} = \text{n. fruit clusters} \times \text{n. fruiting seasons per year} \times 400$$

Following basic criteria were used to investigate flowering and fruiting cycles of *Calophyllum inophyllum* L.

(1) Flowering initiation and secession;
(2) Fruiting initiation and secession;
(3) Floral life span (period from flower bud to fruit bud);
(4) Fruit life span; time between emergence (fruit bud) and abscission (fruit fall);
(5) Mean number of flowers in an inflorescence (different maturity stages);
(6) Mean number of drupes per fruit cluster (different maturity stages);
(7) Quantitative assessment of floral and fruit development.

Analysis

After testing for normality and homogeneity of error variances data were subjected to ANOVA using MINITAB 14.1.

Results and discussion

Flowering initiation and secession

Flowering within each country (different locations) was found to be synchronous and hence partially suppress the issue of the smaller sample size. The Second flowering period in Yeppoon initiates between April-May (Personal observation, 2009) and the second flowering in Meegoda usually begins in October (Personal observation, 2008). Long term mean monthly rainfall data (Fig 1.) shows that flowering initiation in both the locations overlaps with peak rainfall months. Some authors have also reported gregarious anthesis in *Dendrobium crumenatum* and *Coffea arabica* few days after rain (Seifriz 1923; Holdsworth 1961). It is possible that, flowering and fruiting behaviour is strongly regulated by environmental parameters.

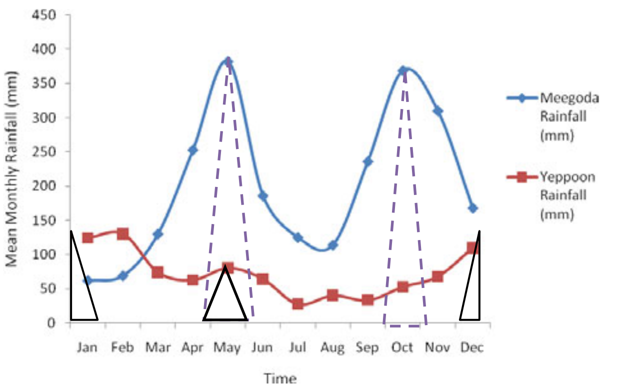

Fig. 1 Long term rainfall pattern in Yeppoon, Australian and in Meegoda, Sri Lanka

Flowering period in Yeppoon; Flowering Period in Meegoda

First flowering period of *Calophyllum* trees in Yeppoon, Australia occurred at the end of December and continued till the end of February. This observation was consistent with those for *Calophyllum* trees in Darwin Australia (Friday and Okano 2006). *Calophyllum* trees in Yeppoon have demonstrated relatively

shorter (≈ 40 days) flowering period compared to those in Meegoda (Fig. 1).

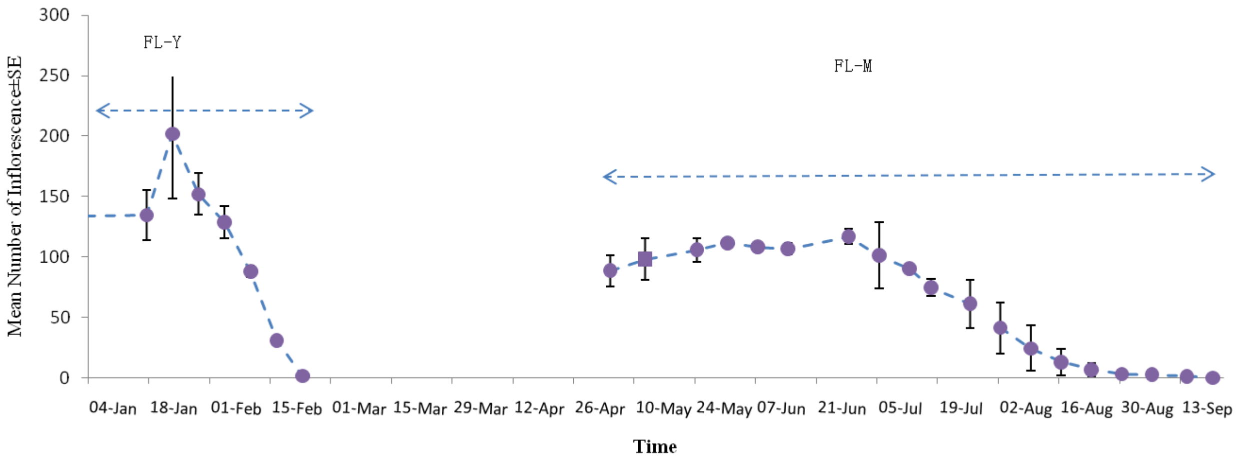

Fig 2. Flowering periods and number of inflorescence in Yeppoon Australia and Meegoda, Sri Lanka at different observation, FL-Y-flowering in Yeppoon, FL-M-flowering in Meegoda.

Corresponding flowering season in Meegoda Sri Lanka started at the end of April and partially ceased at late August. Trees in Meegoda had few flowers even after the climax of fruiting. Similar observations to above have also been reported by Foxworthy (1927) in Malaysia. In contrast to Yeppoon, *Calophyllum* trees in Meegoda Sri Lanka were observed to have longer (≈ 109 days) flowering pattern (Fig. 2). Flower bearing in a given observation was higher in trees from Yeppoon than those from Meegoda.

Floral and fruit development

C. inophyllum trees in Meegoda, Sri Lanka had a floral lifespan of 28 to 31 days (Fig. 3) and it was longer than that of *C. inophyllum* trees in Yeppoon, Australia which had a lifespan of 18 to 20 days (Fig. 3). Mean diameter of mature flowers of *C. inophyllum* trees in Yeppoon, Australia (10.8 mm) was lower than that of *C. inophyllum* trees in Meegoda, Sri Lanka (12.5 mm).

Fruit lifespan of *C. inophyllum* trees in Yeppoon (61 days) was slightly longer than that of Meegoda (56 days). Mature *Calophyllum* fruits in Yeppoon had higher mean diameter (32.4±1.5 mm) compared to those in Meegoda (25.16±1.4 mm). Relationship between altitude and seed size has been well documented (Mazer and Wolfe 1998; Lopez et al. 2003; Loha et al. 2006). Altitude of Meegoda is relatively higher than that of Yeppoon. Hence, the difference in the average fruit size in *Calophyllum* trees from those locations may be due to their relative difference in altitude.

During maturity green-coloured fruits develop yellow patches and on maturity it becomes more greenish yellow. *C. inophyllum* trees in Meegoda had five fruit cycles and those in Yeppoon had four fruit cycles.

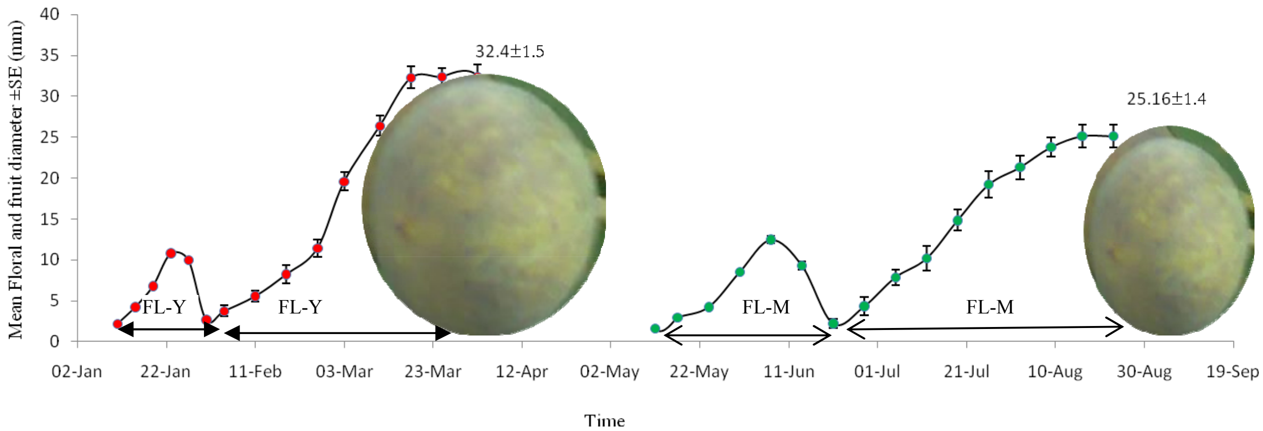

Fig. 3 Floral and fruit development with time, FL-Y-floral development in Yeppoon, FL-M-floral development in Meegoda, FR-Y-fruit development in Yeppoon, FR-M- fruit development in Meegoda.

Early inflorescence of *C. inophyllum* trees in Meegoda had significantly higher ($p < 0.05$) number of flower buds compared to those found in Yeppoon (Table 2). Compared to *C. inophyllum* trees in Yeppoon, those in Meegoda had higher number of intermediate flowers/inflorescence. Mean number of mature flowers per inflorescence was 4 for *C. innophyllum* trees in Yeppoon and

5 for Meegoda and the difference was not statistically significant (Table 2). Both *C. innophyllum* trees in Yeppoon and Meegoda recorded the same mean number of fruit buds/cluster. Mean number of intermediate fruits in a given cluster was higher in *C. innophyllum* trees in Yeppoon than those in Meegoda.

That trend for the number of intermediate fruits/cluster for the two locations remained the same for the number of mature fruits/cluster, but the difference was significant (p < 0.05), which indicates the presence of barren flowers and floral abscission in both the locations.

Table 2. Variation in different stages of floral and fruit development and estimated fruit and oil yield.

Provenance	Different stages of flower (n=3*20)			Different stages of fruit (n=3*20)			Yield (per 400 trees)		
	NFLB	NIFL	NMFL±SD	NFRB±SD	NIFR±SD	NMFR	FRY ·ha^{-1}·a^{-1}	KW kg·ha^{-1}·a^{-1} ±SD	Oil kg·ha^{-1}·a^{-1} ±SD
Yeppoon	7a	5a	4±1.12	4±0.8	4±0.9	4b	664000a	2988.0±853.2	1332.6±380.5
Meegoda	9b	7b	5±1.52	4±0.9	3±1.12	3a	934000b	3390.4±613.2	1071.0±190.7

Within column mean values that are followed by different letters are significantly different at p<0.05 level. NFLB-number of flower buds/inflorescence, NIFL-number of intermediate flowers/inflorescence, NMFL-number of mature flowers/inflorescence, NFRB-number of fruit buds/cluster, NIFR- number of intermediate fruits/cluster, NMFR-number of mature fruits/cluster, FRY-fruit yield, KW- weight of kernels. *KW (kg·ha^{-1}·a^{-1}) and Oil (kg·ha^{-1}·a^{-1}) were determined by using mean kernel weights and mean kernel oil contents for two locations reported by Hathurusingha et al. (2010).

The difference in the number of flowers /inflorescence could be due to the difference in orientation and distance between those trees in above locations. *Calophyllum* trees in Yeppoon occurred in a straight line and ≈ 12 m apart from one another and those in Meegoda were at least 100 m apart from one another and were far more scattered. Due to their proximity from one another and linear orientation, *C. inophyllum* trees in Yeppoon probably have lesser competition for pollination; whereas those in Meegoda may have produced more flowers and barren flowers to attract pollinators.

C. inophyllum trees in Meegoda had significantly higher (p < 0.05) fruit yield compared to those in Yeppoon (Table 2). It may be due to longer fruiting period and higher number of fruiting cycles in Meegoda, compared to that of Yeppoon. When resources are limited, plants may produce fewer larger seeds or many smaller seeds (Harper et al. 1970). Stressful environmental conditions (e.g. drought) more often than not favour selection of larger seeds as they provide more reserves for successful establishment of seedlings (Moles and Westoby 2004). *Calophyllum* trees in both the locations are facing environmental stress, where those in Yeppoon are growing on sandy soils and those in Meegoda are growing on heavy clay soils. Clay soils have less concentration of air-filled pores. Abundance of air-filled pores is important for plant growth (Wall and Heiskanen 2009). Trees in Yeppoon are experiencing periodic drought and those in Meegoda are slow growing due to poor root respiration in compact clay soils.

Slower growth in Meegoda may have induced the production of smaller seeds. In both locations, trees under comparison were growing without any maintenance, hence it should be noted that yield can be raised considerably if maintained properly.

However, oil (kg·ha^{-1}·a^{-1}), and weight of kernels (kg·ha^{-1}·a^{-1}) in Yeppoon was higher than that of Meegoda (Table 2). Higher kernel weights in Yeppoon may be due to its stress induced selection (Moles and Westoby 2004) and or lower altitude (Loha et al. 2006). Rose (1988) observed an increase in oil content of soybeans under drought stress. Higher oil yield in Yeppoon may also due to periodic drought.

Floral and fruit abscission and reproductive success

In a given inflorescence of *C. innophyllum* trees in Yeppoon, 57% of flower buds developed into mature flowers. Similar trend (55%) was observed among those trees in Meegoda. All fully developed flowers of *C. inophyllum* trees in Yeppoon and 80% of fully developed flowers of *C. inophyllum* trees in Meegoda became fruit buds (Fig. 4). Mean floral abscission in *C. inophyllum* trees from Meegoda (44.4%) was slightly higher than that in *C. inophyllum* trees from Yeppoon (42.8%). *C. innophyllum* trees found in both Meegoda and Yeppoon demonstrated similar mean fruit abscission (25%).

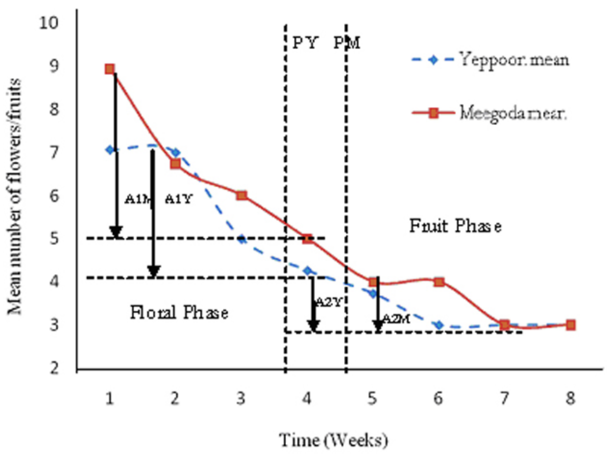

Fig. 4 Floral abscission (A1) and fruit abscission (A2) in selected inflorescence of *Calophyllum inophyllum* trees in Yeppoon, Australia and Meegoda Sri Lanka (PM-pollination in Meegoda, PY-pollination in Yeppoon, Observations (1-1st observation, 2-1 week, 3- 2 weeks, 4-6 weeks, 5-8 weeks, 6-10 weeks).

Conclusion

Calophyllum inophyllum trees in Australia and Sri Lanka demonstrated considerable variations in flowering and fruiting phenology. Flowering initiation in both locations indicated a hint of dependency on rainfall pattern. *C. inophyllum* trees in Yeppoon, Australia had relatively shorter flowering periods, shorter floral life spans, longer fruit life spans, smaller flowers and larger fruits compared to those in Meegoda, Sri Lanka. Even though mean number of flower buds/ inflorescence was higher in Meegoda, *C. inophyllum* trees at both the locations had similar mean number of mature fruits/ cluster due to the higher floral abscission in *C. inophyllum* trees in Meegoda. Despite producing a lower fruit yield, *C. inophyllum* trees in Yeppoon had higher kernel weights and oil yield compared to those in Meegoda.

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